Exploring the Dynamic Interplay Between Charging Infrastructure Expansion and Electric Heavy Truck Adoption

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KTH ROYAL INSTITUTE OF TECHNOLOGY

The transition of the road freight transport system

7%

Transition to sustainable system

Electrification

| Market share of new EVs in 2022 Sweden	
2%	Heavy trucks
32%	Passenger Cars
14%	Light Trucks
19%	Buses

Ref: Trafikanalys

Research Questions

- How can the dynamic relationship between charging infrastructure expansion, market adoption, and policy interventions of heavy electric trucks be described?

- What role can different policy interventions play in the adoption of heavy electric trucks?
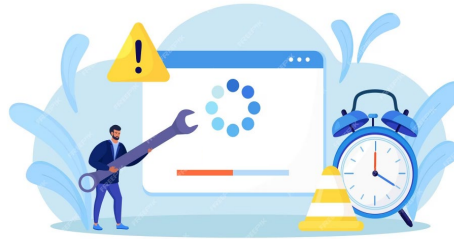
A chicken-egg problem

Electric Trucks → **+** → **Charging Infrastructure** → **+** → **Electric Trucks**
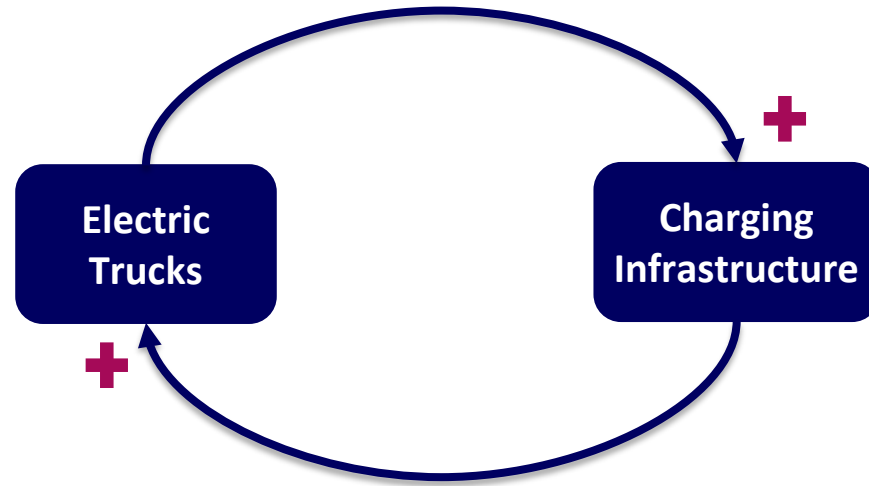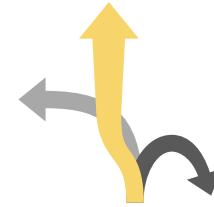
Why system dynamics?
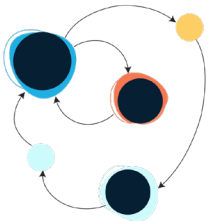## Key features of complex dynamics system
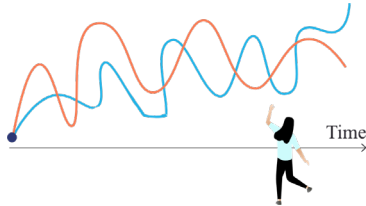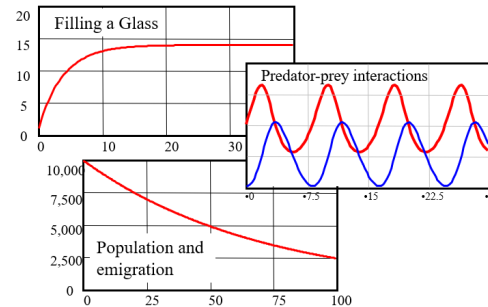

dynamic: changing over time

delays

diversity of actors and stakeholders
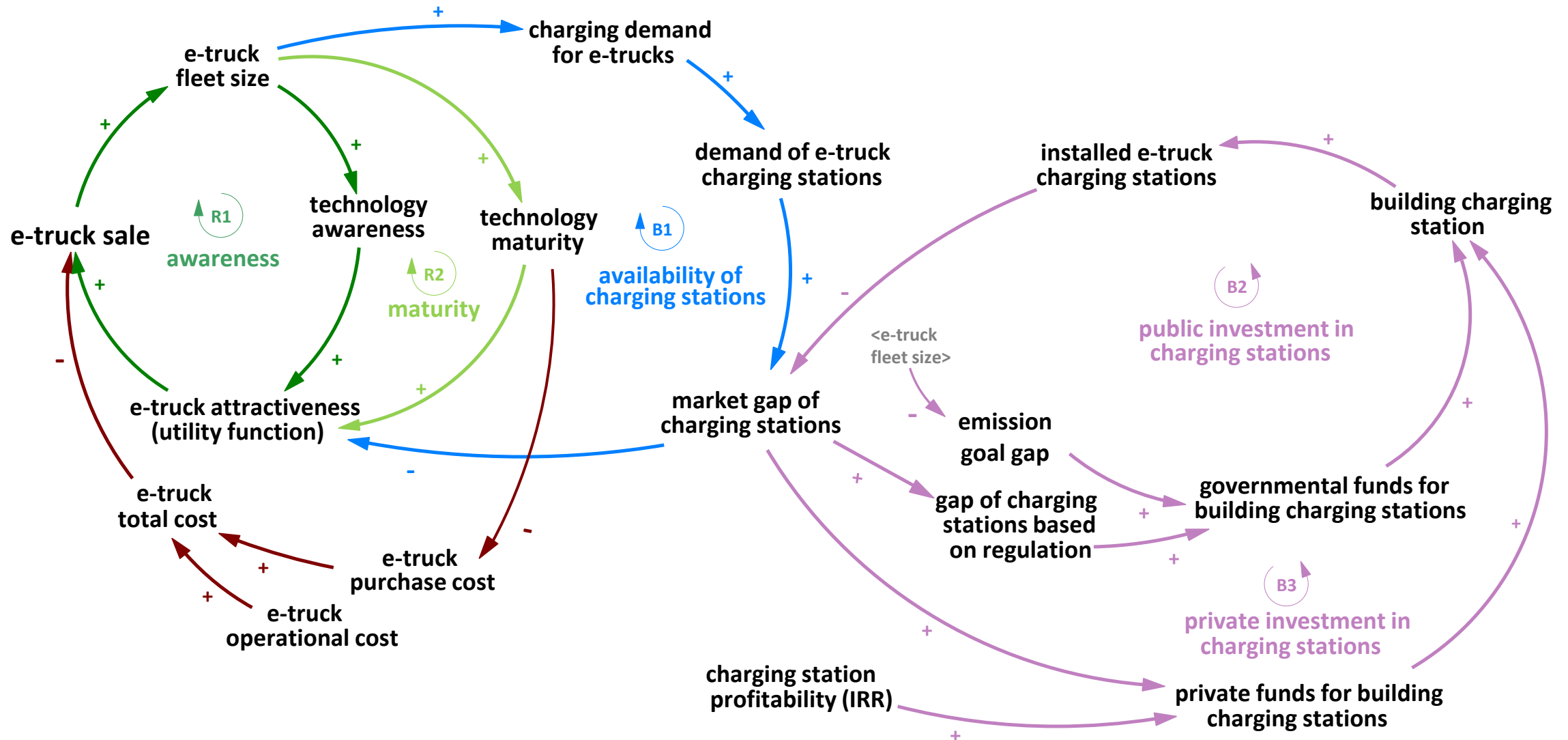

feedback & rebound effect

nonlinearities

policy setting

Exploring the dynamics:
Charging station development and electric truck adoption

Potential policy intervention
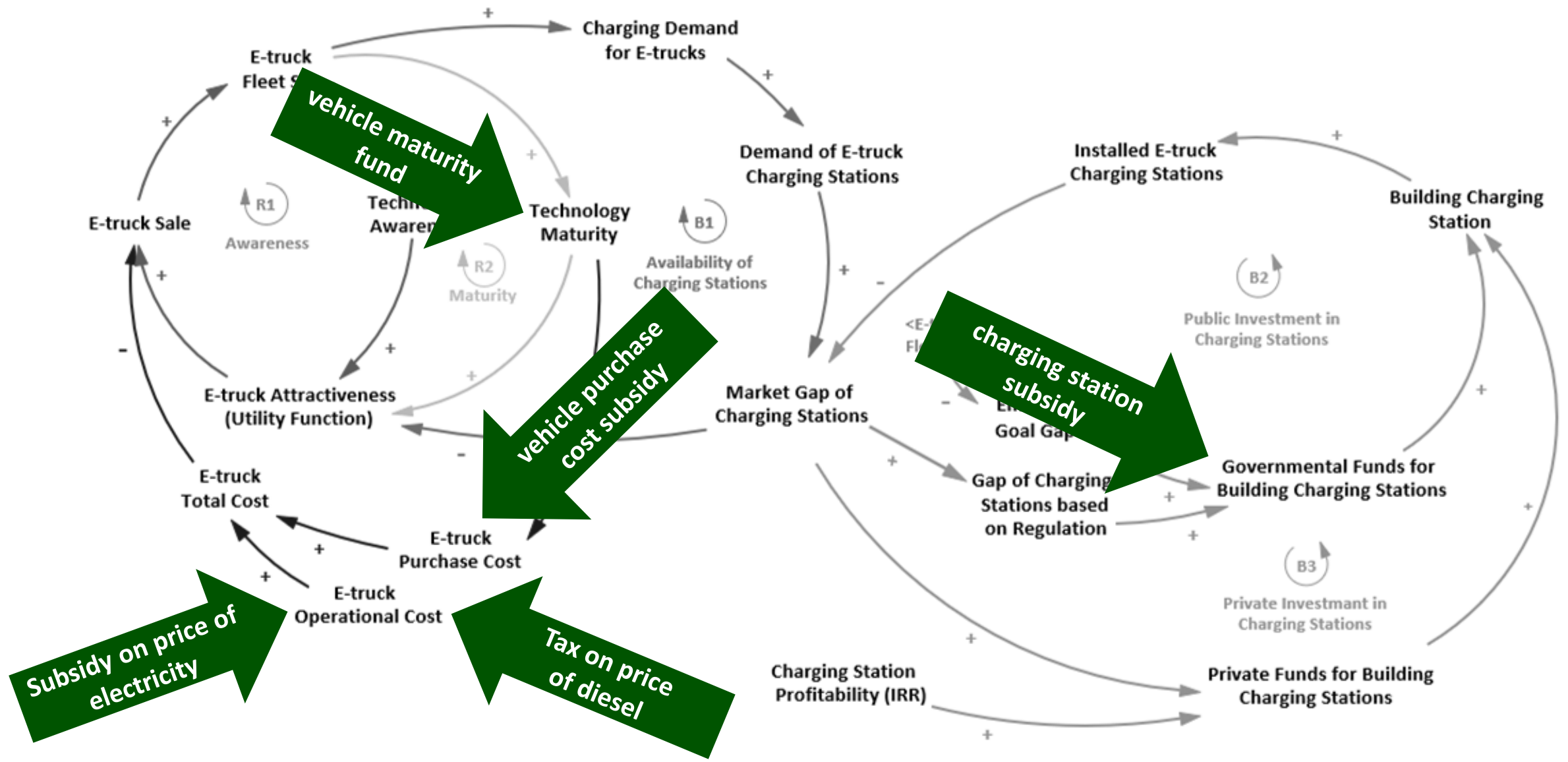
System dynamics model
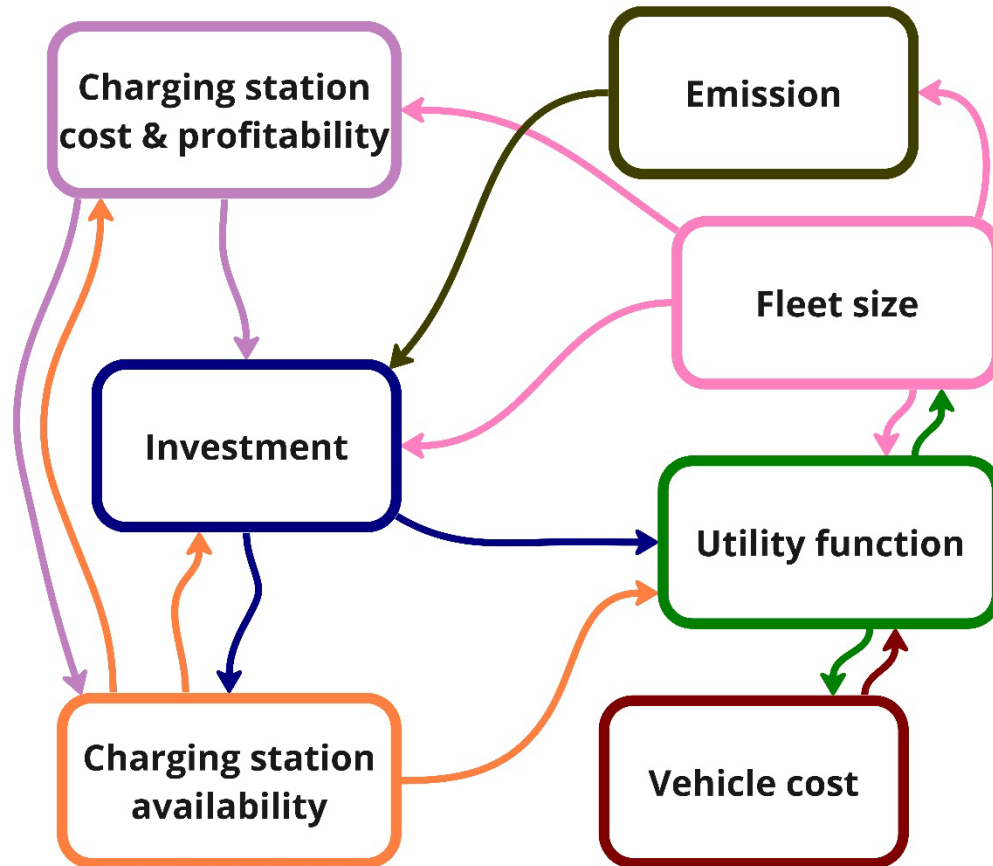
Variables	253
Sub-models	7
Stocks	17
Flows	23
Converters	213
Constants	55
Equations	181

Model development and assumptions

Model structure and equations
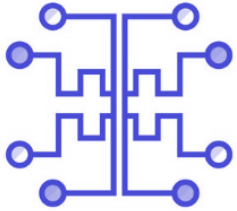
real system
Sweden 🇸🇪
2017-2060

literature

expert interviews

modeling and validation workshops

participatory modeling

Model structure and assumptions

Model structure and equations

real system

literature

participatory modeling

Sweden 🇸🇪

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expert interviews

modeling and validation workshops

Data collections

European Commission

European Alternative Fuels Observatory

European EV Charging Infrastructure Masterplan

March 2022

acea
DRIVING MOBILITY FOR EUROPE

KLIMAT KLIVET
Lokala klimatinvesteringar. Mätbara resultat.

REEL
Regional Electrified Logistics

TRAFIKVERKET

/// Mobility Sweden

TRAFIK ANALYS

SCB

Energimyndigheten

Model structure and assumptions

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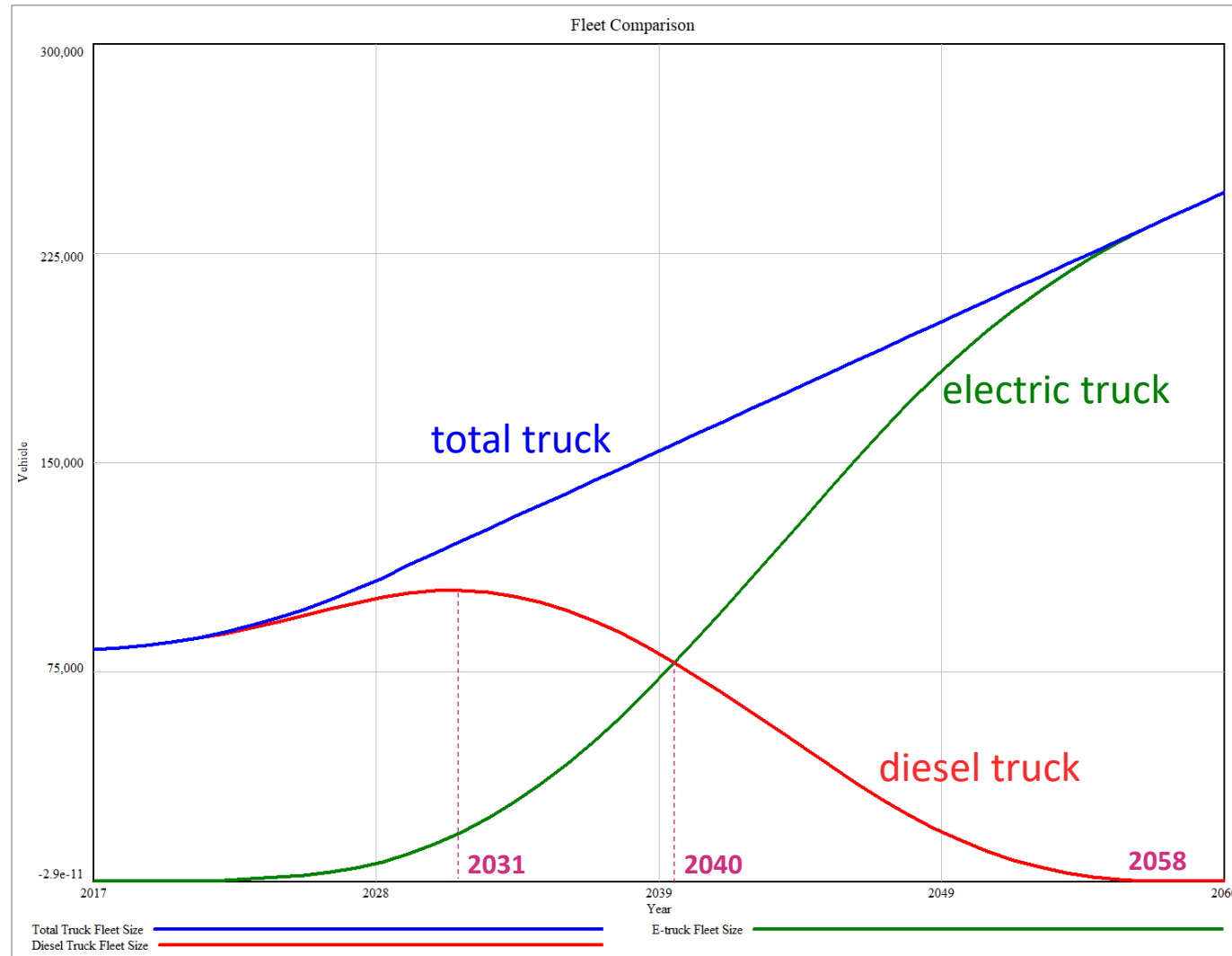TRAFIKVERKET

TRAFIK ANALYS

SCB

Energimyndigheten

Main assumptions

- focus solely on electric vs. diesel trucks

- heavy truck class: +3.5 ton

- equal average mileage and lifetime for electric and diesel trucks

- sales of total trucks

- aggregated different types of stationary charging

- public sector role, as in Sweden

Number of electric trucks vs. diesel trucks

Fleet Comparison

Comparison of government investments

Comparison of various government investments

Potential policy intervention
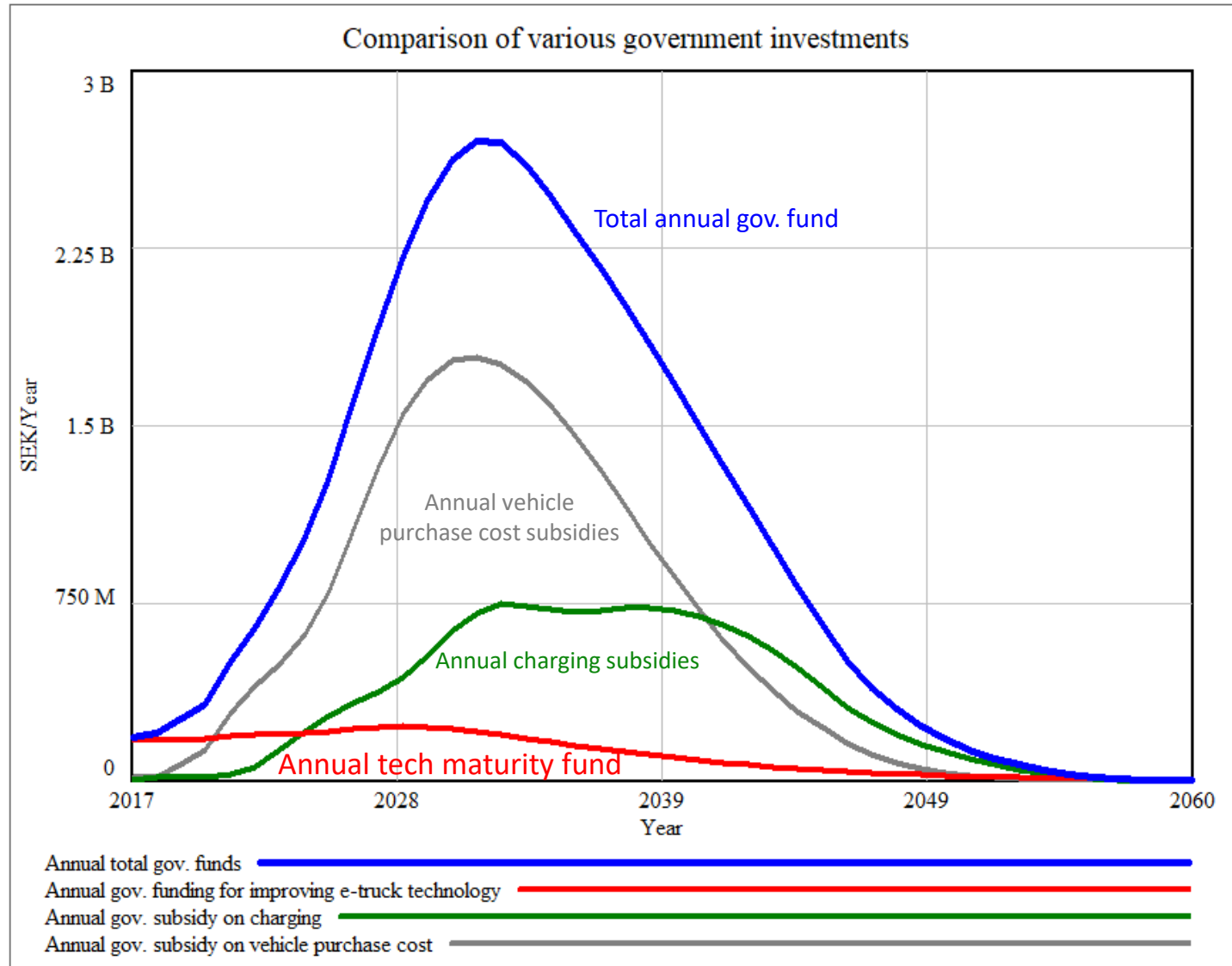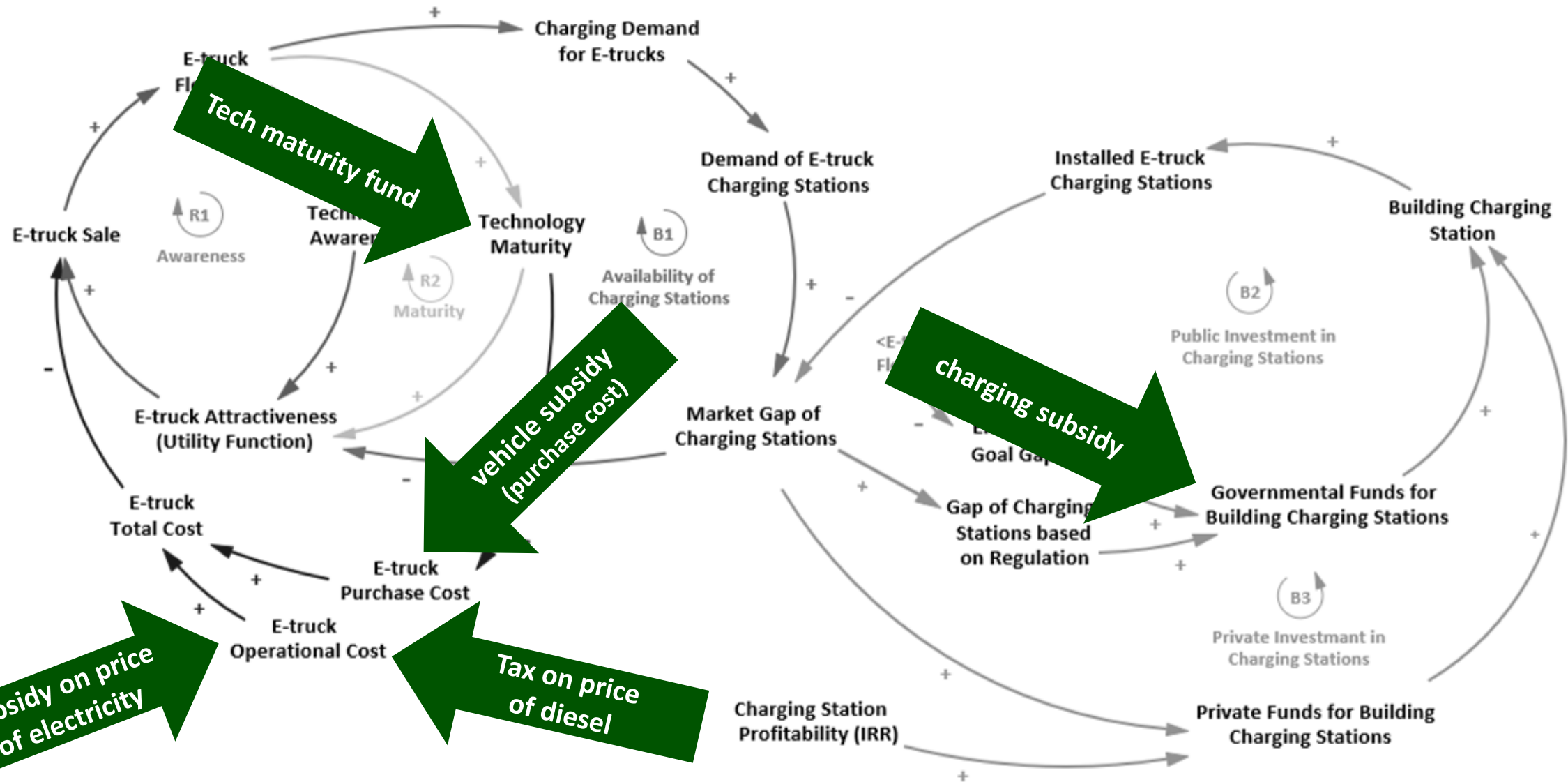
Sensitivity analysis:
Market share of electric trucks by ±20% changes in different policy levers
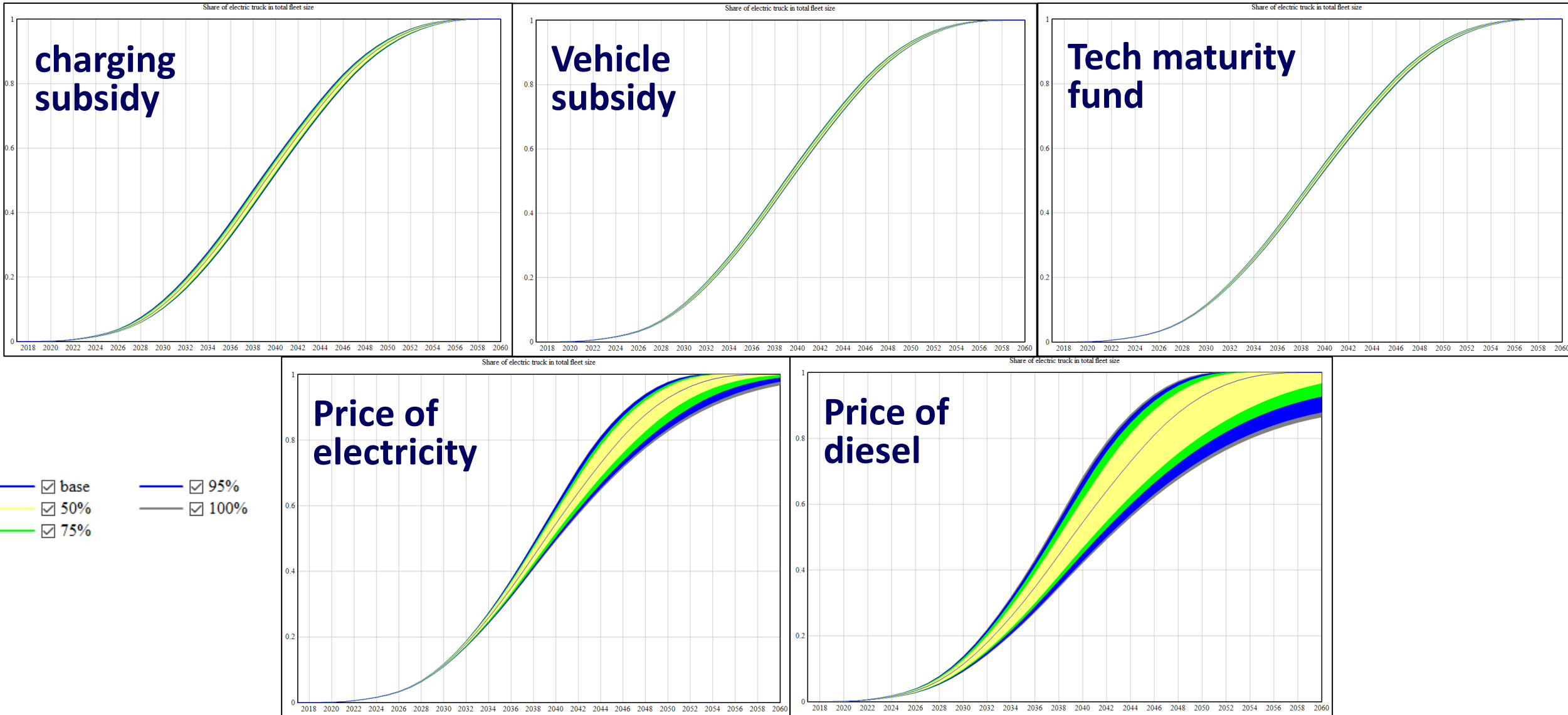
Policy efficiency ratio *(vehicle/SEK)* $=$ $$\frac{\text{Change in the number of vehicles by the specific policy } \textit{(vehicle)}}{\text{Change in the amount of investment by the specific policy } \textit{(SEK)}}$$

Scenario descriptions

Market share of electric trucks in different scenarios

Share of electric truck in total fleet size

Legend:
- Low Electrification
- Base
- High Electrification
- Unstable Policies

Base ——— High Electrification ———
Low Electrification ——— Unstable Policies ———
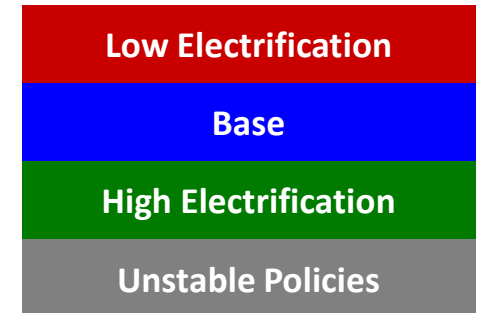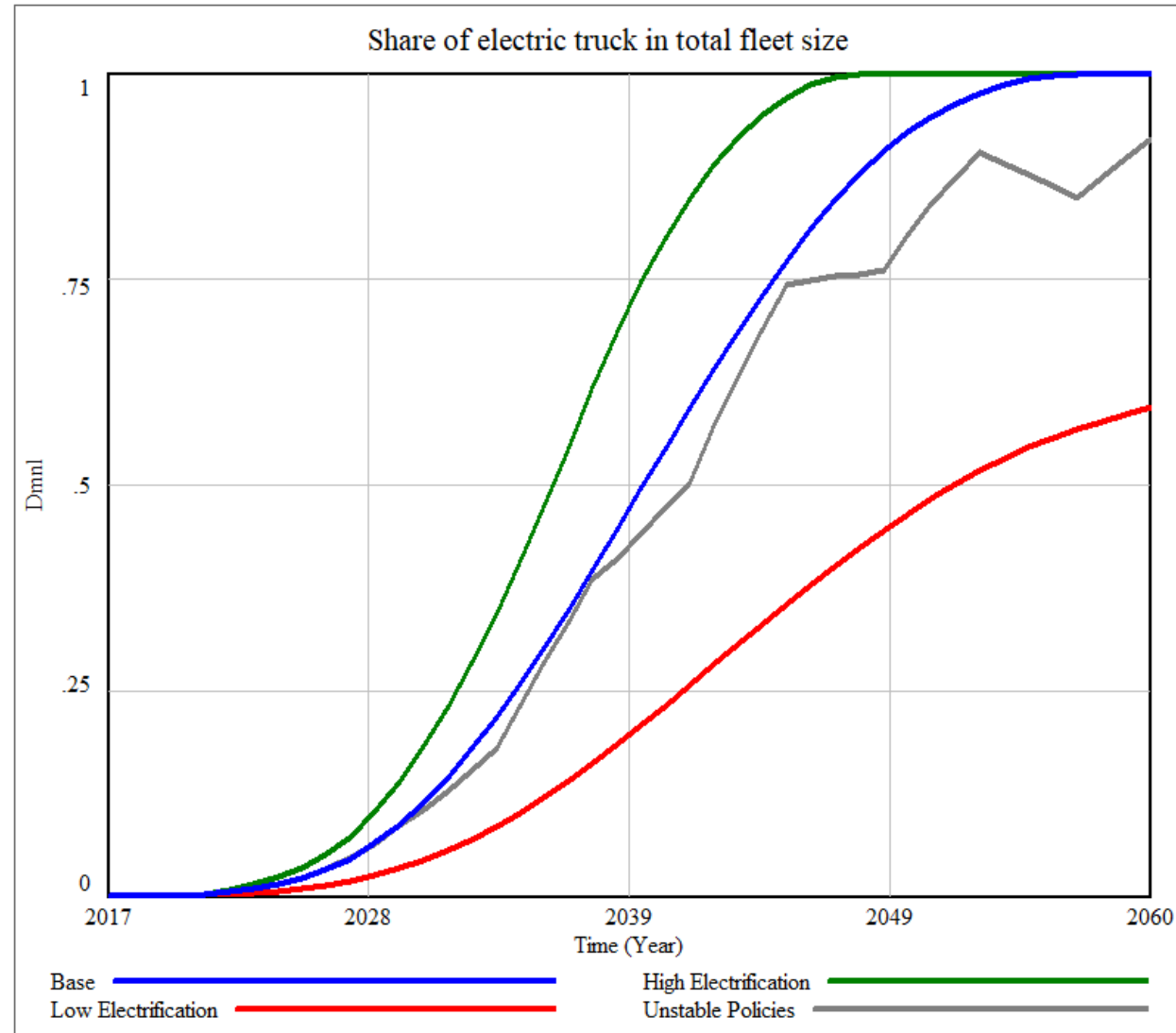
Do we reach our emission goal in Sweden?

Sweden's reduction CO2 emission goal in transportation:
70% in 2030 & net-zero by 2045 (compared to 2010)

Do we reach our emission goals?

Legend:
- Low Electrification (red)
- Base (blue)
- High Electrification (green)
- Unstable Policies (gray)

- Total annual emissions: Base
- Total annual emissions: Low Electrification
- Total annual emissions: High Electrification
- Total annual emissions: Unstable Policies
- Goal of emission level in 2030
- Goal of emission level in 2045
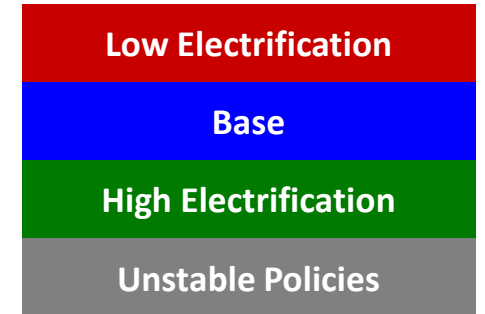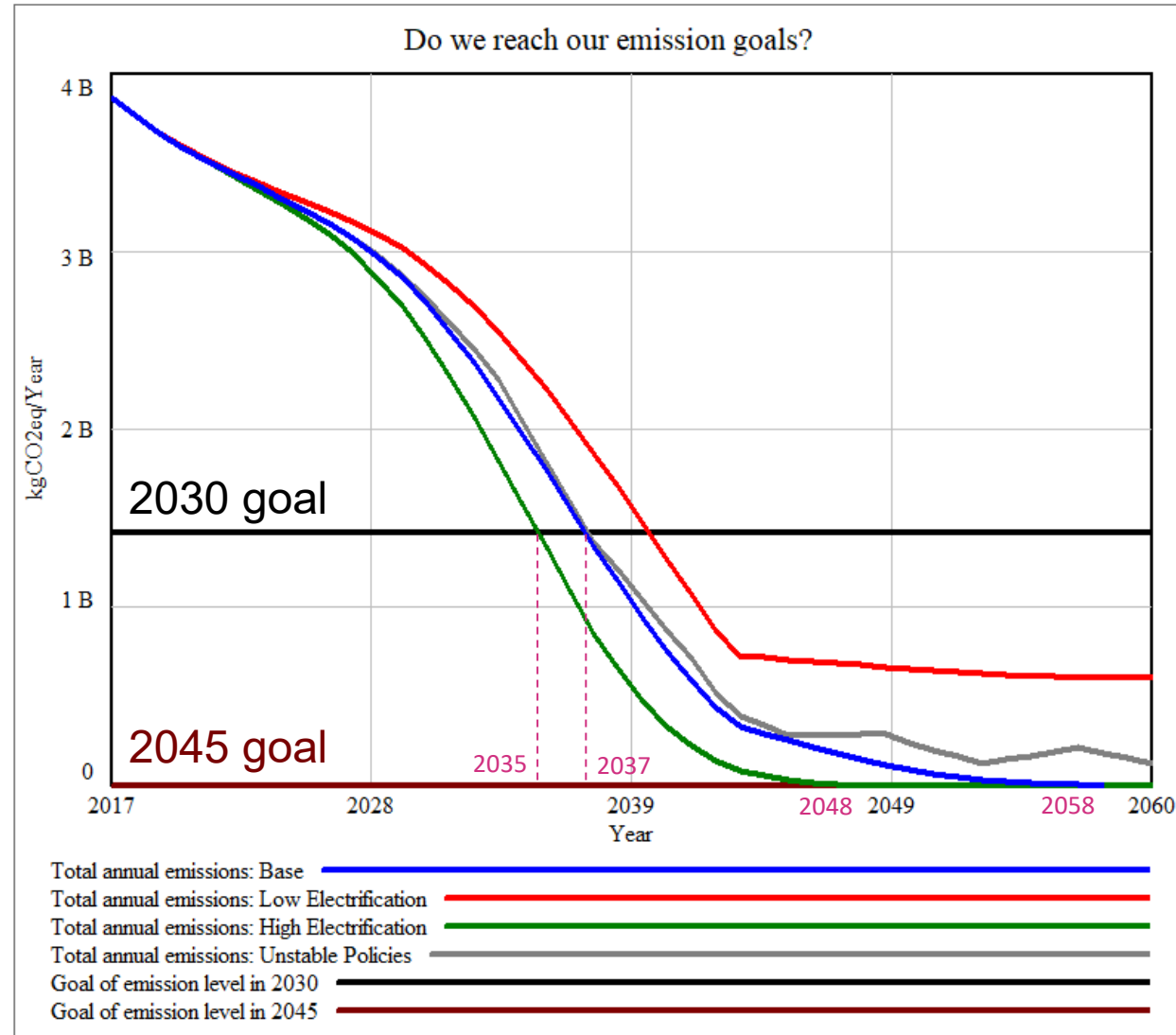
Main takeaways

1 Electrification **triggers several feedback loops and rebound effects** and raises new questions and trade-offs.

2 Policy **intervention plays an important role**: policymakers must consider dynamics when allocating budgets

3 The impact of electricity and diesel prices on the adoption of electric trucks.
After reaching near-maximum utility, the fight is on the cost.
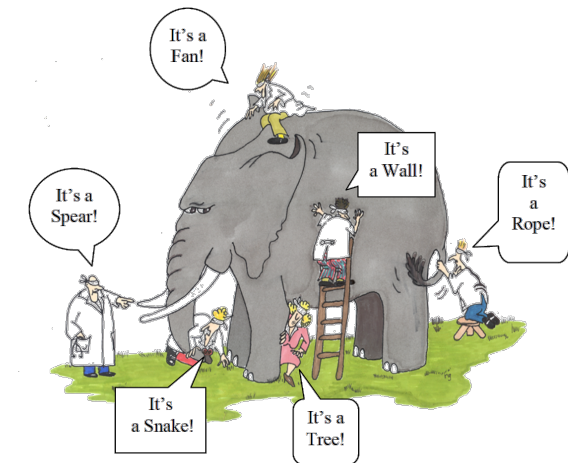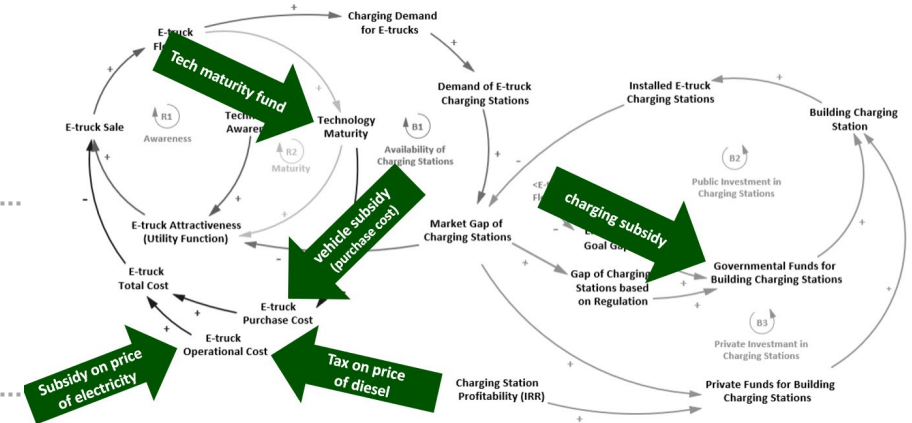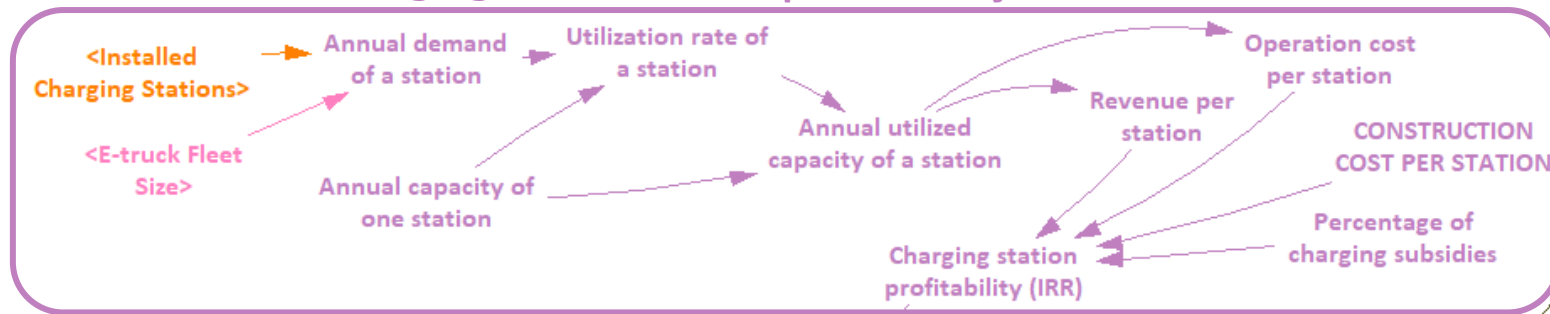
4 System Dynamics could be useful for demonstrating the dynamics and ripple effect through the system.

Contact:
Anna Pernestål
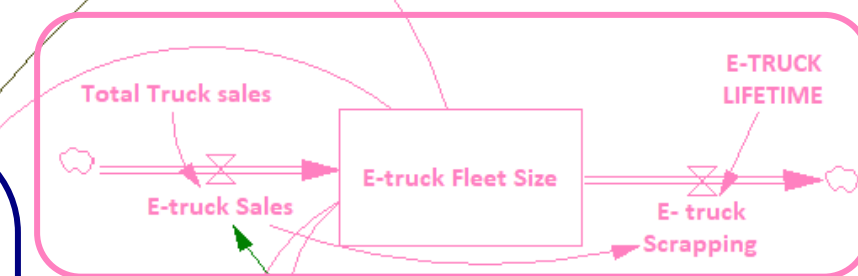annapern@kth.se

Appendix Figures
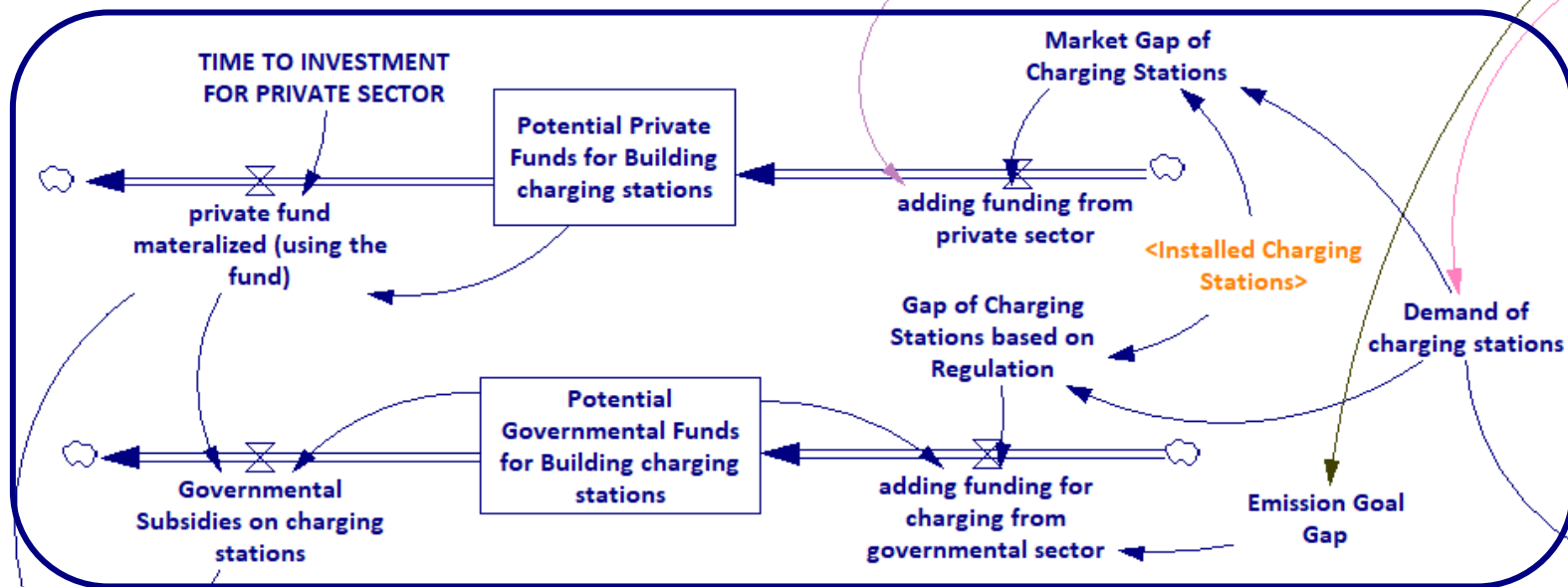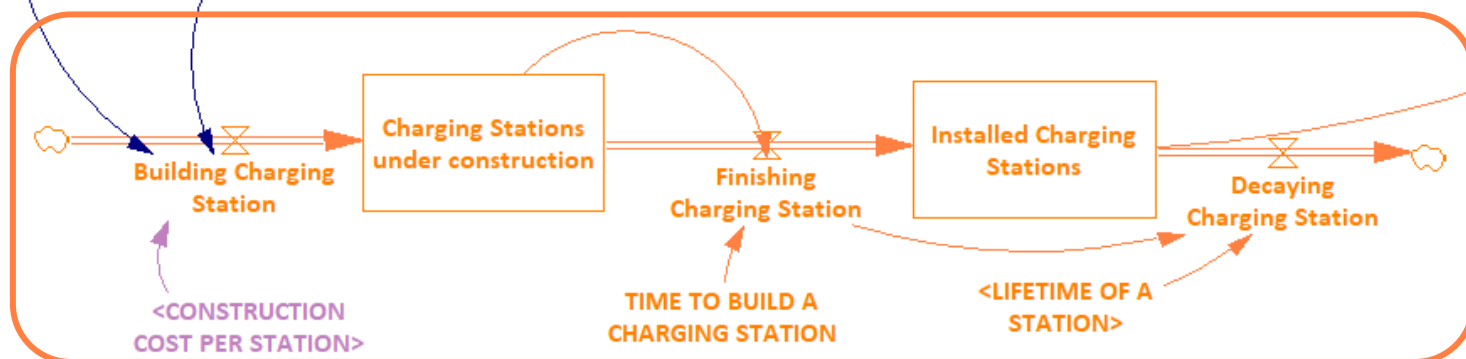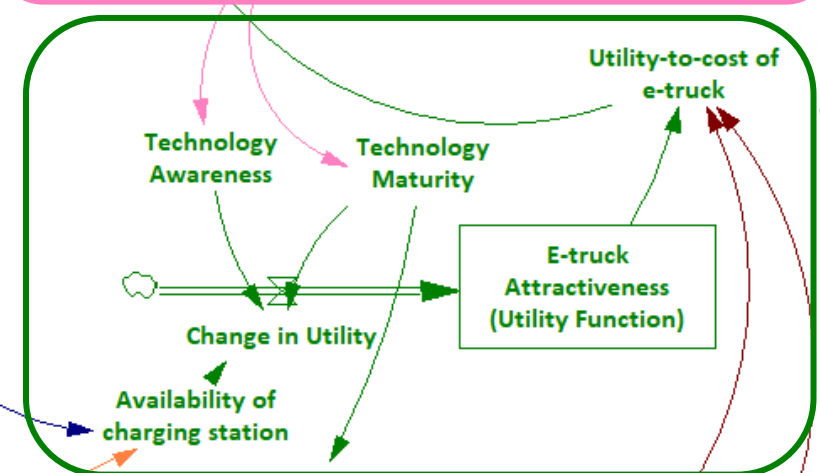
Charging station cost & profitability module

<Installed Charging Stations> → Annual demand of a station → Utilization rate of a station

<E-truck Fleet Size>

Annual capacity of one station → Annual utilized capacity of a station → Revenue per station → Operation cost per station

CONSTRUCTION COST PER STATION

Charging station profitability (IRR) ← Percentage of charging subsidies

Emission module

Total annual emission from trucks (tank to wheel) ← Carbon intensity of diesel vs. electricity

Fleet size module

Total Truck sales

E-truck Sales

E-truck Fleet Size

E-TRUCK LIFETIME

E- truck Scrapping

Investment module

TIME TO INVESTMENT FOR PRIVATE SECTOR

Potential Private Funds for Building charging stations

Market Gap of Charging Stations

private fund materalized (using the fund)

adding funding from private sector

<Installed Charging Stations>

Gap of Charging Stations based on Regulation

Demand of charging stations

Governmental Subsidies on charging stations

Potential Governmental Funds for Building charging stations

adding funding for charging from governmental sector

Emission Goal Gap

Utility function module

Utility-to-cost of e-truck

Technology Awareness

Technology Maturity

E-truck Attractiveness (Utility Function)

Change in Utility

Availability of charging station

Charging station availability module

Building Charging Station

Charging Stations under construction

Finishing Charging Station

Installed Charging Stations

Decaying Charging Station

<CONSTRUCTION COST PER STATION>

TIME TO BUILD A CHARGING STATION

<LIFETIME OF A STATION>

Vehicle cost module

E-truck Purchase Cost

E-truck Operational Cost

Electric truck total cost

Diesel truck Purchase Cost

Diesel truck total cost

Diesel truck Operational Cost
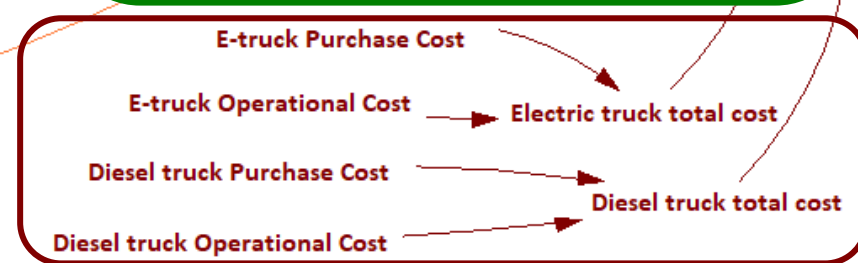
Base scenario results
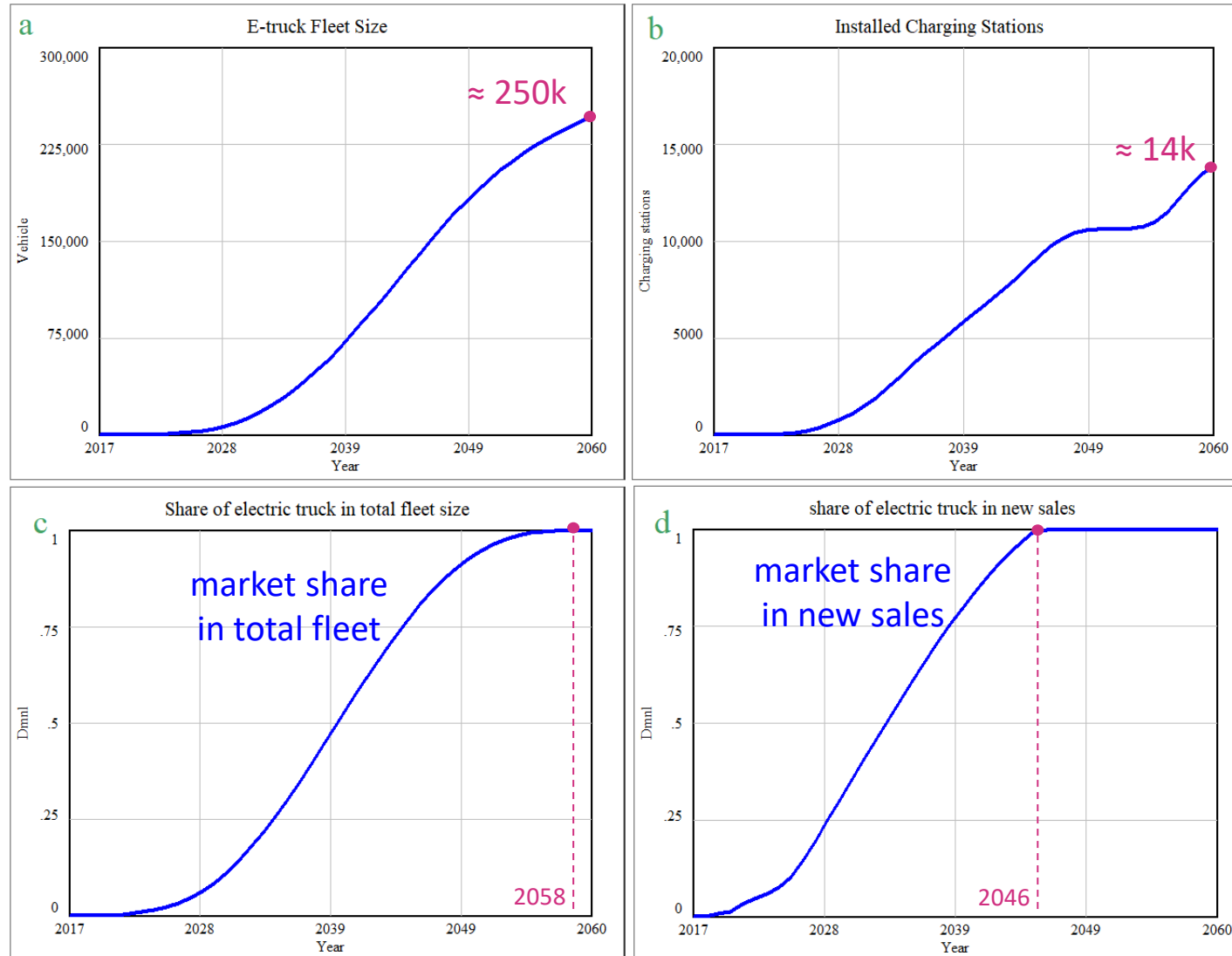
Utility Function

Comparison of government investments
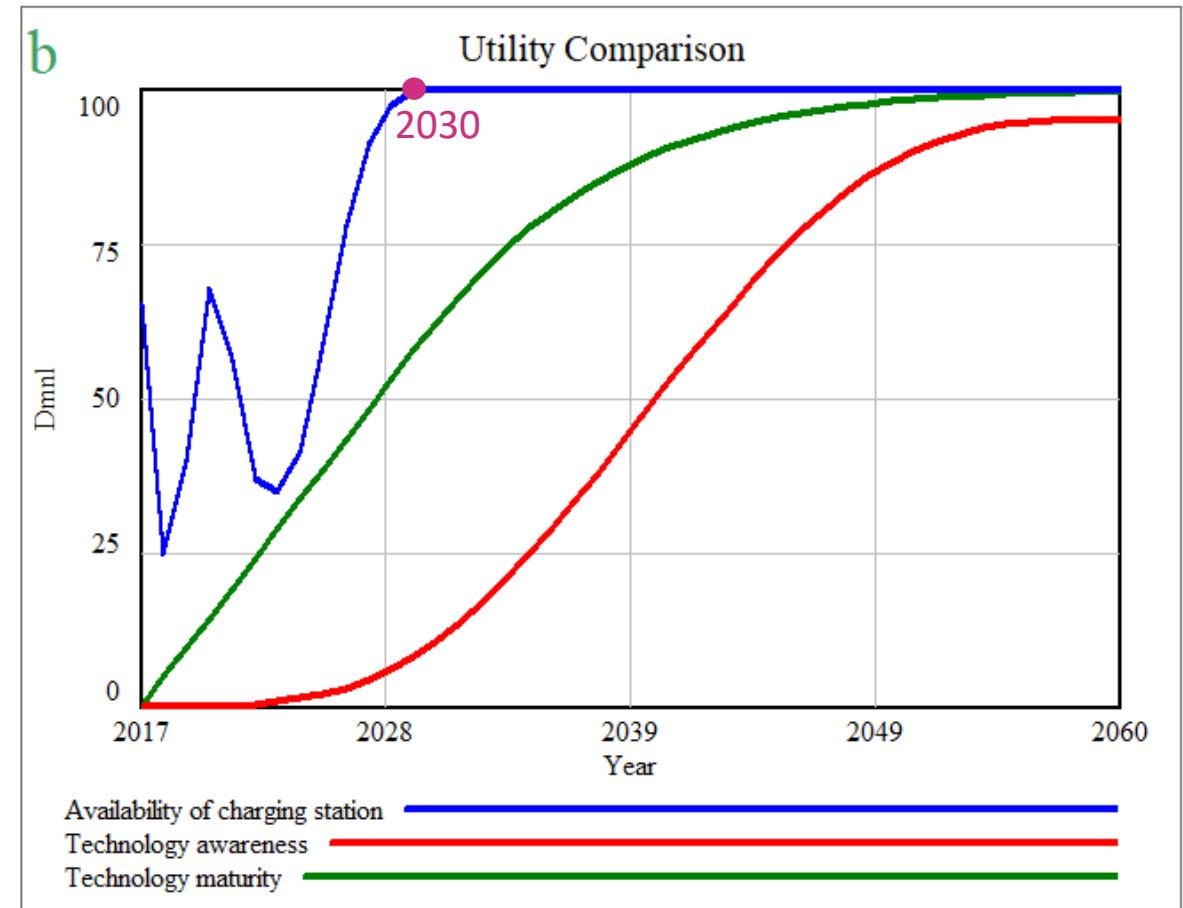
Comparison of various government investments
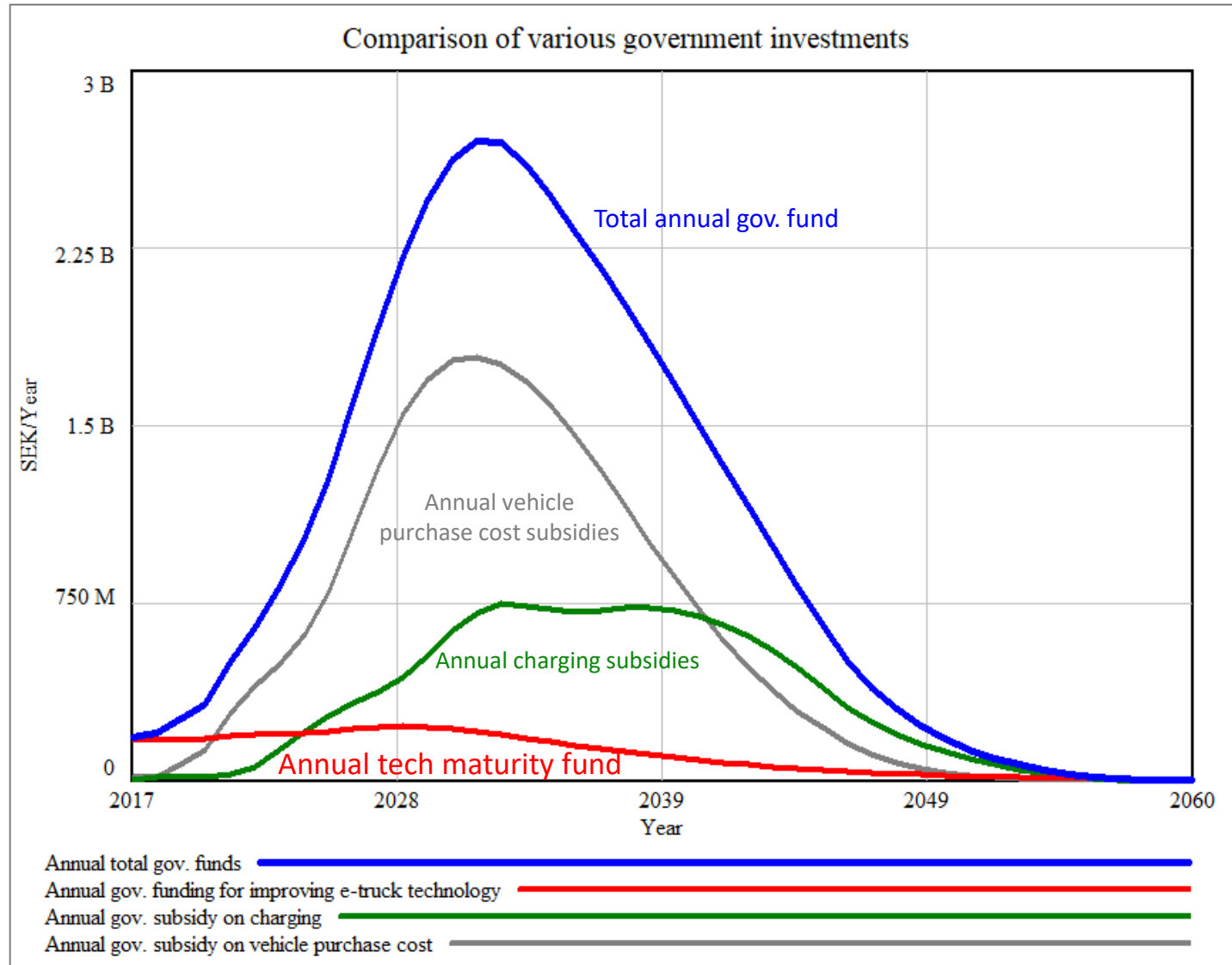
Private vs. Gov Investments in Charging Stations
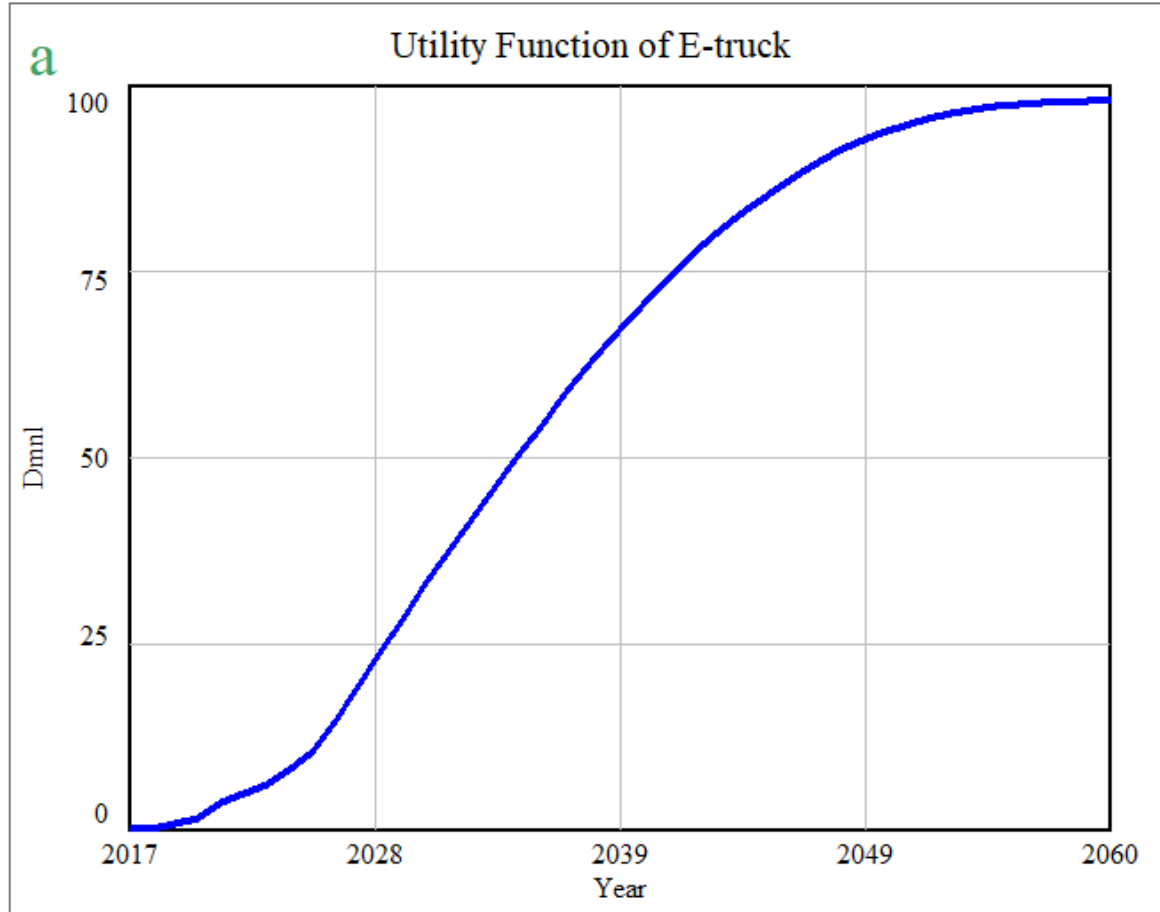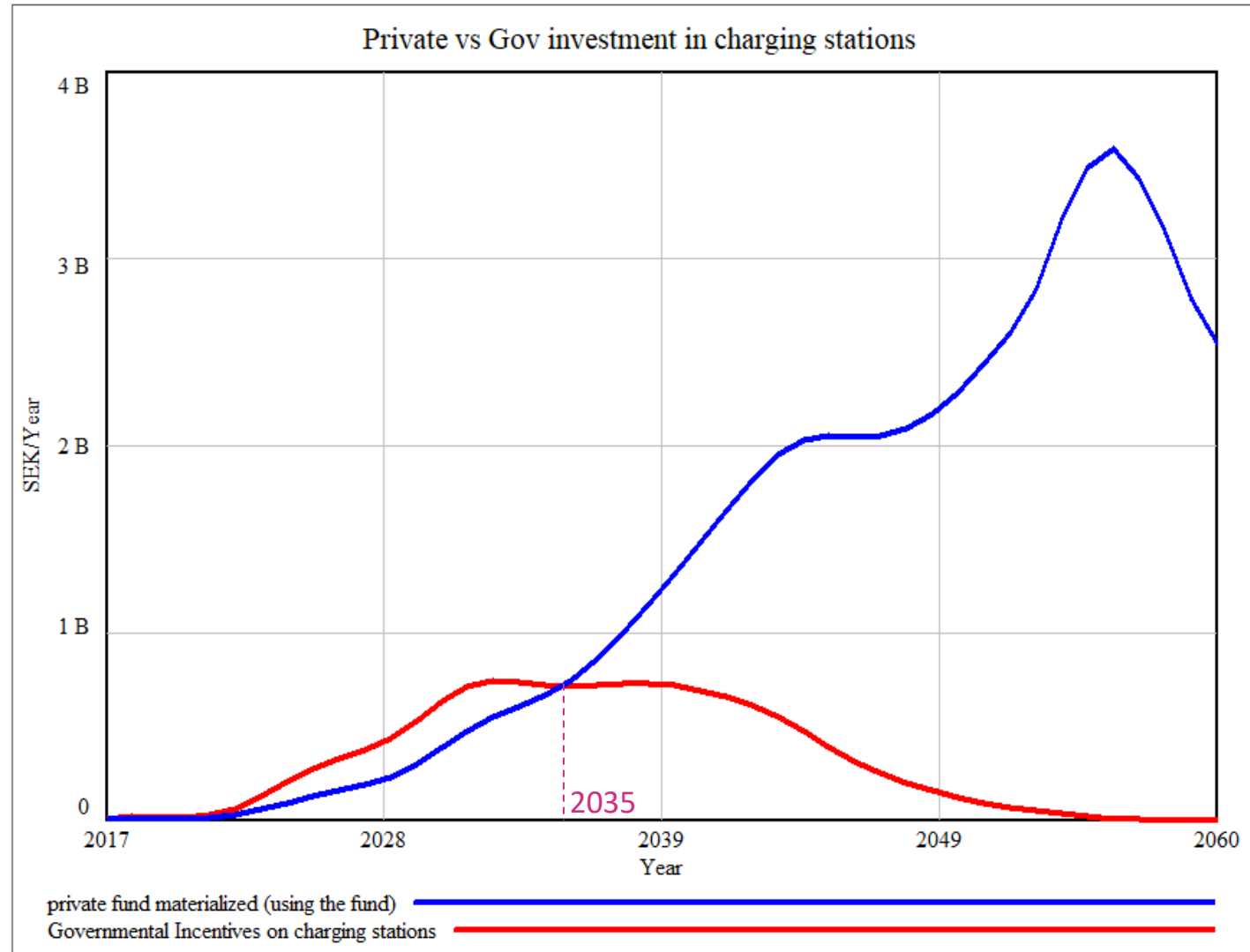
Key variables diagrams
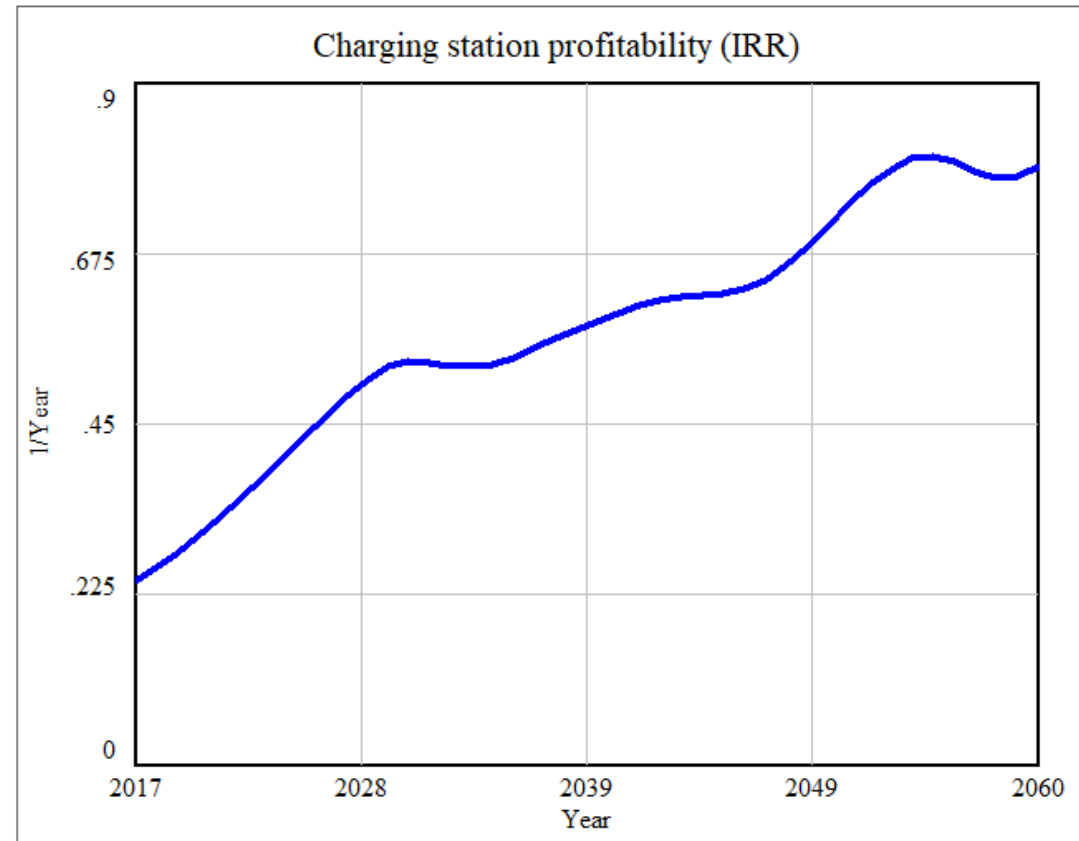
Key variables diagrams
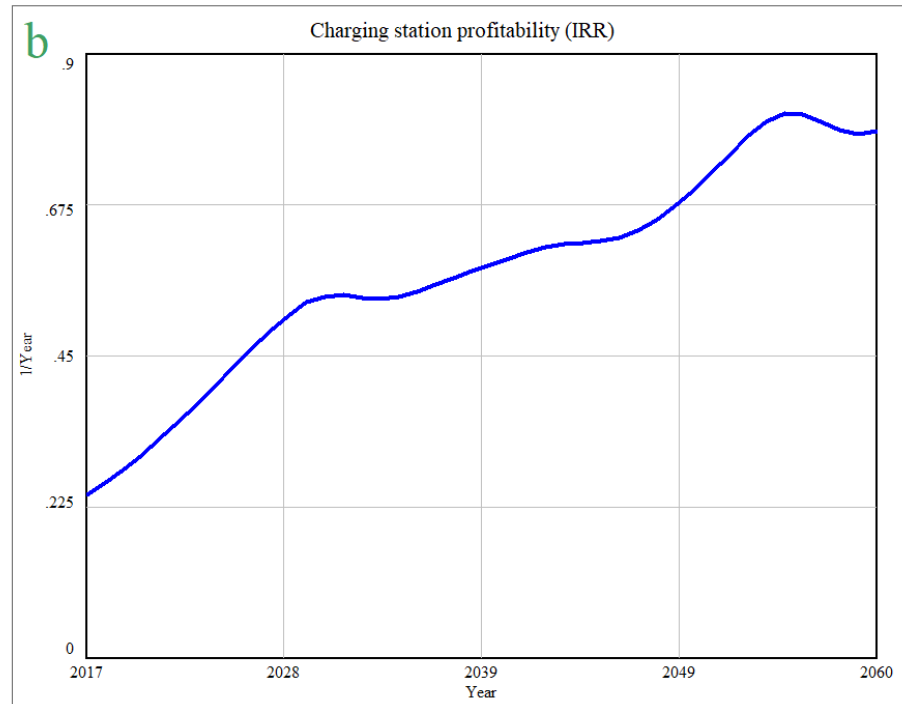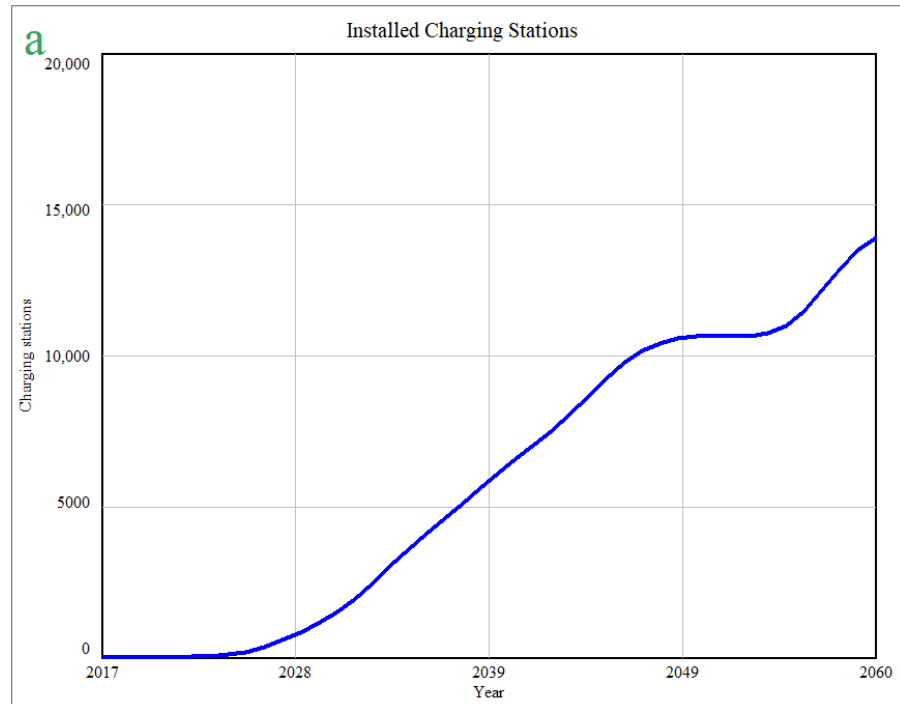
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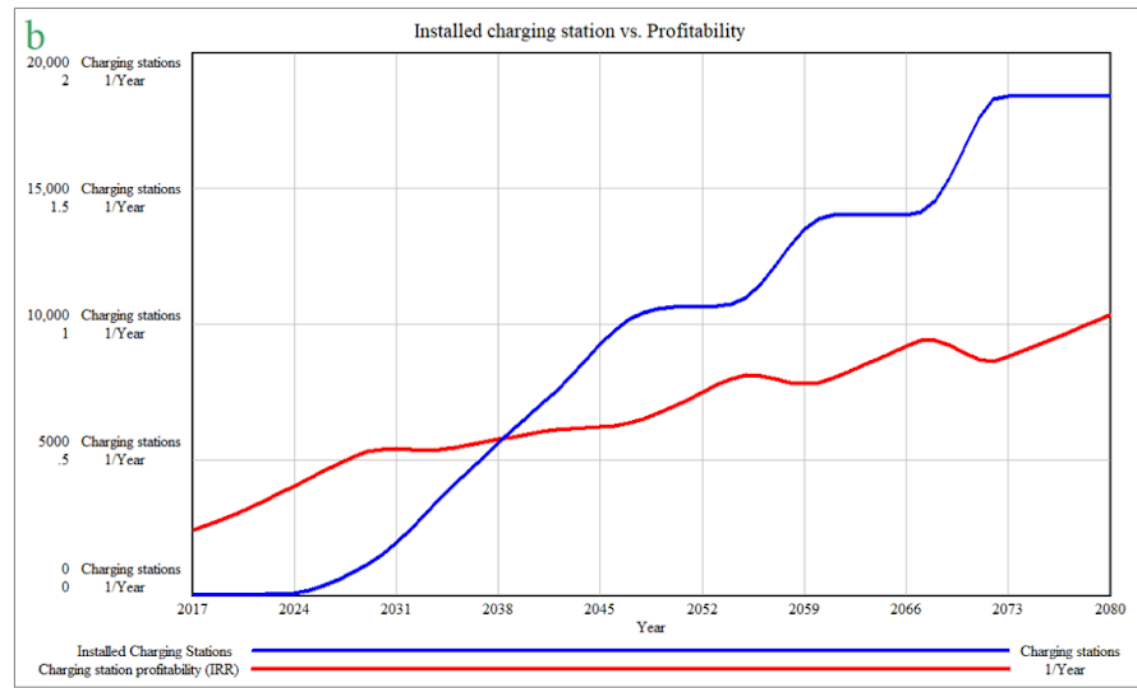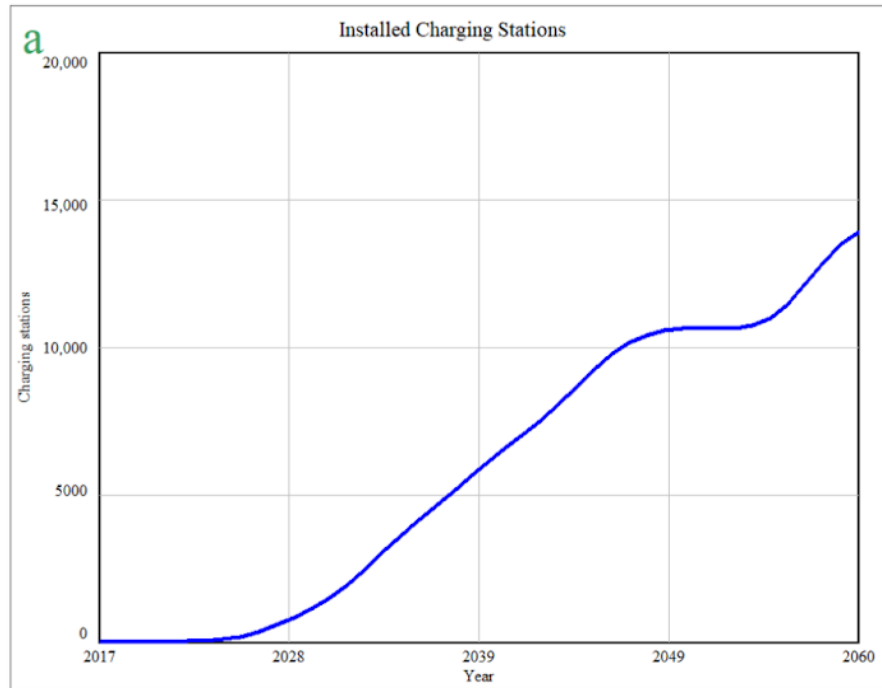
Price of electricity and how it affects the model

Price of electricity and how it affects the model

a Effect of EL price on the Station profitability

b Effect of EL pric on the market share of elecctric trucks

c Effect of EL Price on the installed charging stations
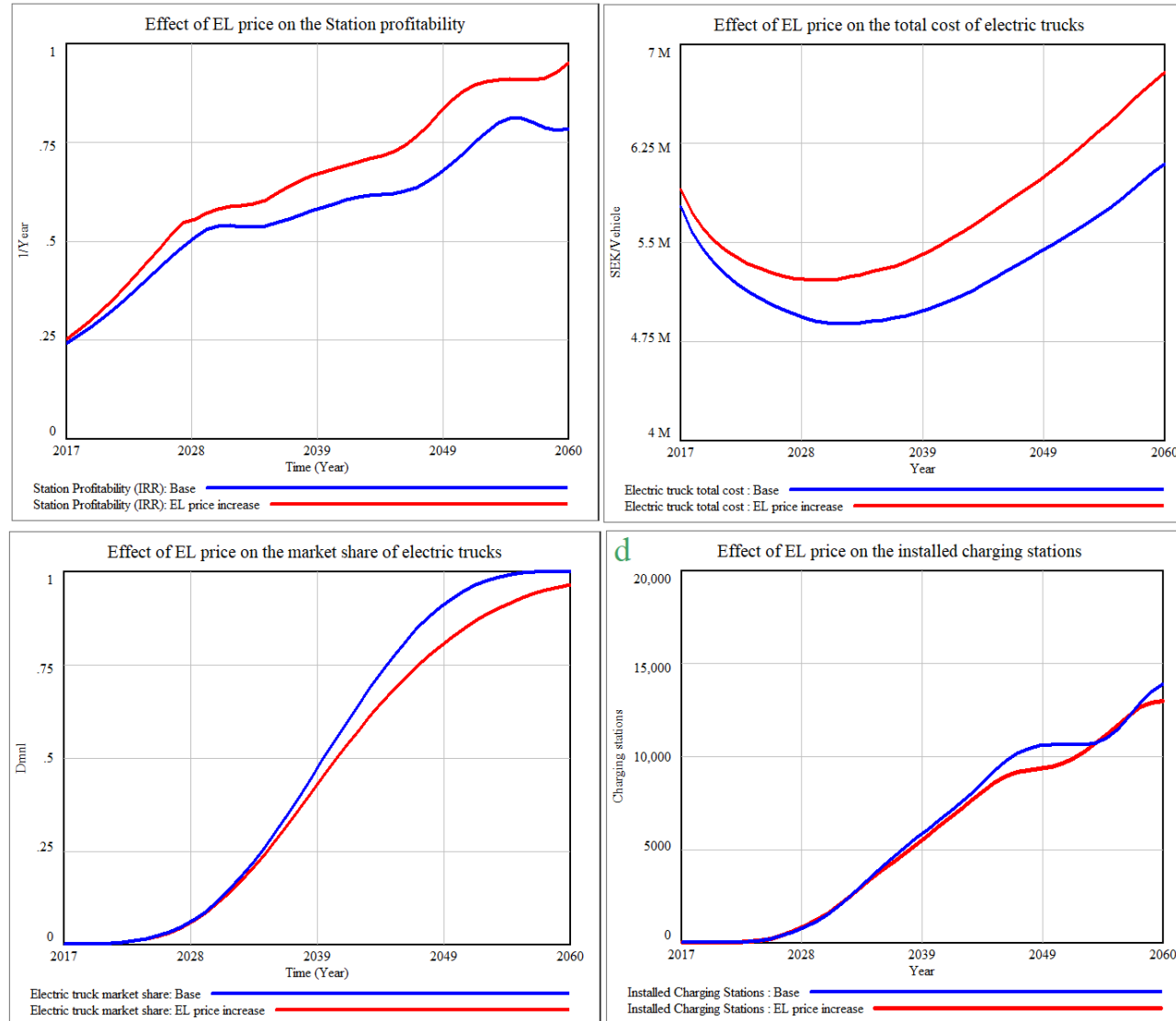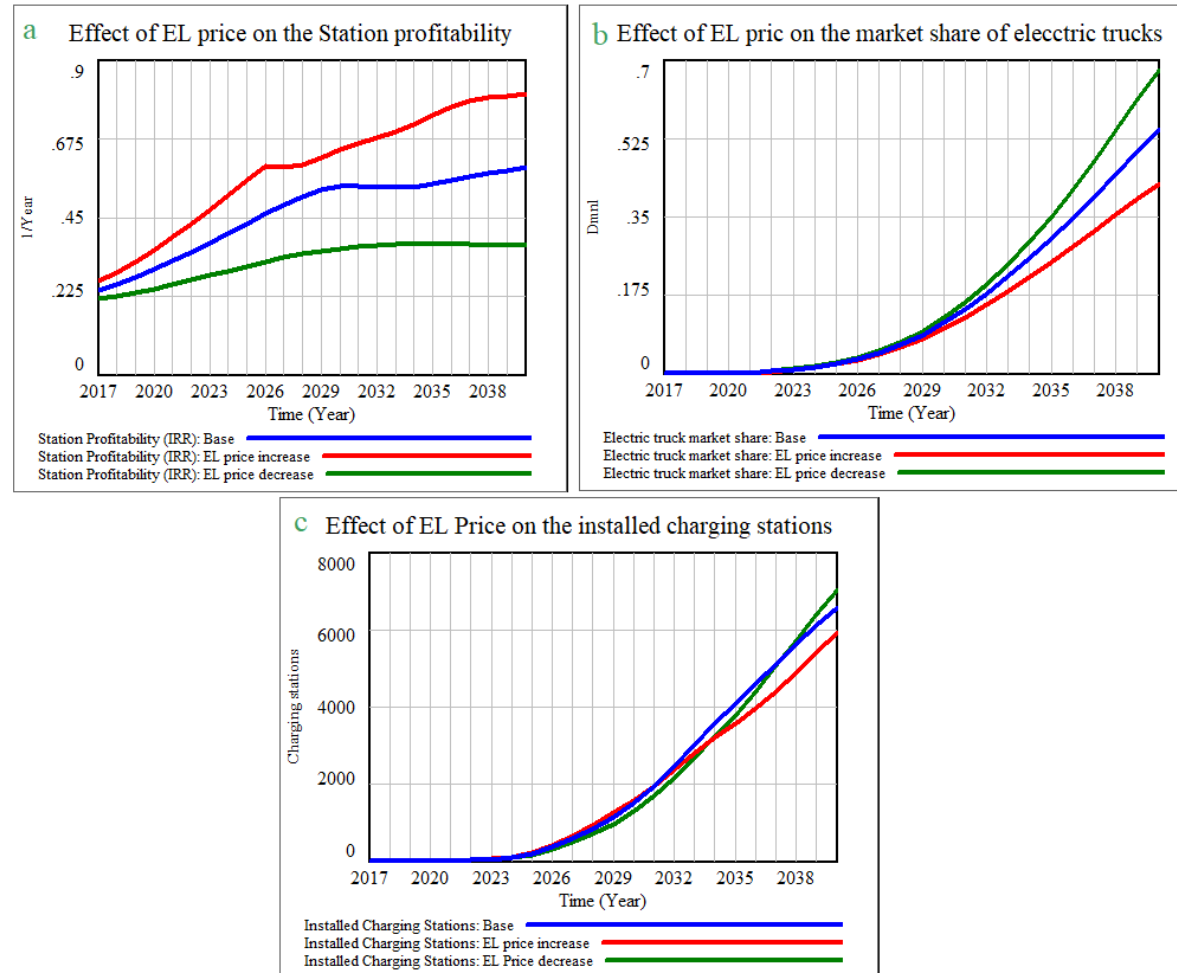
Effect of annual mileage on the market share of e-truck
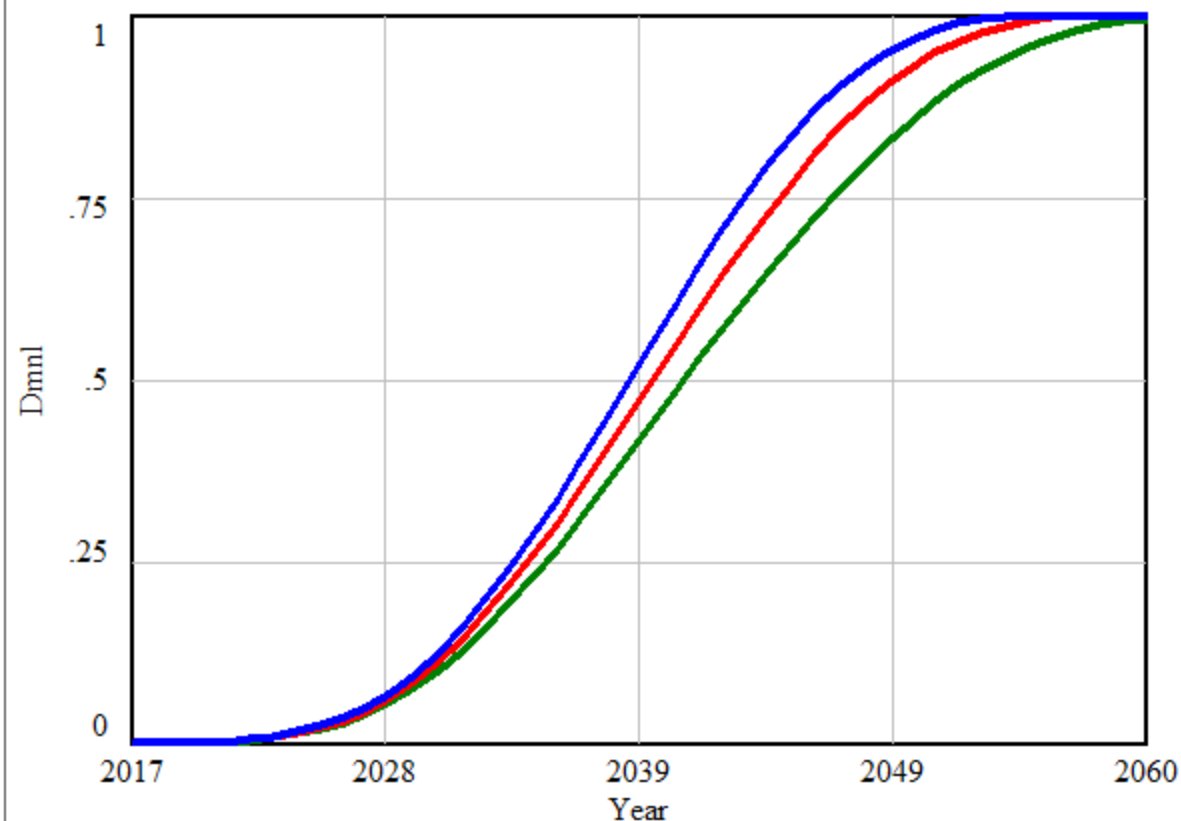
Market share of e-truck in total fleet: High mileage
Market share of e-truck in total fleet: Base
Market share of e-truck in total fleet: Low mileage

b Effect of annual mileage in total cost comparison

Electric truck total cost : High mileage
Diesel truck total cost : High mileage
Electric truck total cost : Base
Diesel truck total cost : Base
Electric truck total cost : Low mileage
Diesel truck total cost : Low mileage

What truck technologies and fuel options cost the least?
Ranking of total cost of ownership for various European truck classes in 2030

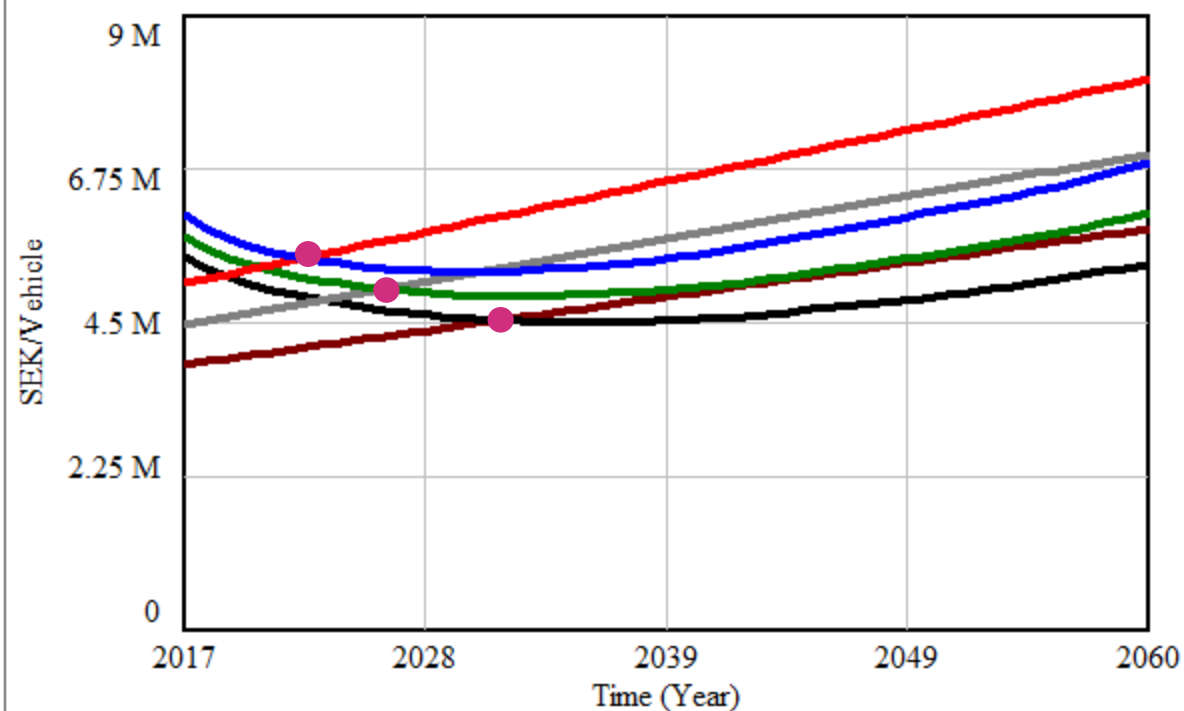|	Long-haul (return-depot - 500 km)	Long-haul (return-depot - 800 km)	Long-haul (cross-border - 1,000 km)	Heavy-duty regional truck	Medium-duty urban truck	Light-duty urban truck
€ Lowest						
	BEV (€0.94/km)	BEV (€0.93/km)	BEV (€0.91/km)	BEV (€0.83/km)	BEV (€0.87/km)	BEV (€1.03/km)
	Diesel (€1.15/km, +22%)	Diesel (€1.13/km, +21%)	Diesel (€1.06/km, +15%)	Diesel (€0.98/km, +18%)	FCV (€1.03/km, +18%)	FCV (€1.18/km, +14%)
	HVO (€1.18/km, +25%)	HVO (€1.16/km, +24%)	HVO (€1.1/km, +20%)	HVO (€1.0/km, +20%)	Diesel (€1.07/km, +23%)	Diesel (€1.19/km, +15%)
	FCV (€1.22/km, +29%)	FCV (€1.24/km, +32%)	FCV (€1.16/km, +27%)	FCV (€1.06/km, +27%)	HVO (€1.09/km, +25%)	HVO (€1.2/km, +16%)
	H₂-ICE-DF (€1.32/km, +40%)	H₂-ICE-DF (€1.3/km, +40%)	H₂-ICE-DF (€1.22/km, +34%)	e-Diesel (€1.12/km, +34%)	e-Diesel (€1.25/km, +44%)	e-Diesel (€1.34/km, +29%)
	e-Diesel (€1.36/km, +44%)	e-Diesel (€1.34/km, +43%)	e-Diesel (€1.27/km, +39%)	H₂-ICE-DF (€1.14/km, +37%)	H₂-ICE-DF (€1.27/km, +46%)	H₂-ICE-DF (€1.36/km, +32%)
	H₂-ICE-SI (€1.38/km, +45%)	H₂-ICE-SI (€1.36/km, +46%)	H₂-ICE-SI (€1.28/km, +40%)	H₂-ICE-SI (€1.15/km, +38%)	Bio-CNG (€1.28/km, +48%)	Bio-CNG (€1.38/km, +33%)
	Bio-CNG (€1.38/km, +46%)	Bio-CNG (€1.37/km, +46%)	Bio-CNG (€1.31/km, +43%)	Bio-CNG (€1.15/km, +38%)	H₂-ICE-SI (€1.36/km, +56%)	H₂-ICE-SI (€1.42/km, +37%)
€€€ Highest						

BEV battery-electric vehicle

HVO hydrotreated vegetable oil *(produced locally from waste oils)*

H₂-ICE-DF hydrogen-diesel dual-fuel engine *(H₂ produced locally)*

FCV fuel-cell vehicle *(H₂ produced locally)*

Bio-CNG bio-compressed natural gas *(produced locally from waste and residue materials)*

H₂-ICE-SI pure hydrogen spark-ignition engine *(H₂ produced locally)*

e-Diesel electro-diesel *(imported from Brazil)*